Flexural Strength and Ductility Behavior of Ferrocement I-Beam

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Abstract

The purpose of this study is to improve the practical use of the ferrocement I-beams by attempting to develop its ductile behavior. Result of the study showed that the compressive strength of the ferrocement mortar used was satisfactory, the welded wire mesh sold in the Philippine market passed the required material properties, hence, it can be used in the ferrocement applications. There is a marked increase in the capacity of the ferrocement I-Beam as the number of layers of wire mesh reinforcement in the flange area is increased from 8 layers and additional two layers increased per treatment. There is also increasing number of cracks in the flange section as the number of layers of welded wire reinforcement signifying that the beam is already showing ductility behavior.

Keywords: Ferrocement, welded wire mesh, load at failure, ductility behavior

1. Introduction

Ferrocement is a material that has a wide range of applications that include agricultural facilities, rural energy, water supply, repair and rehabilitation and housing. It is defined as a type of thin-wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small-sized wire mesh. The mesh may be made of metallic or other suitable materials (ACI Committee 549). The ferrocement displays a series of advantages as compared to reinforced concrete, among which are a wider range of elasticity; greater resistance to extension; better behavior at dynamic stress; and, increased value of the breaking effort out of extension (Naaman, 2000).

Low-cost housing is a concept which deals with the utilization of effective budgeting and construction technique that helps in reducing cost by using cheap but efficient construction materials, simplified construction procedures with building components pre-manufactured in a factory, hauled and assembled on site. The construction procedure is made simpler without sacrificing strength, performance and life of the structure. One particular part of a building is a simple beam. In the study conducted by Acma (2014), a ferrocement I-beam is formed by creating two ferrocement Channel-beam, reinforced with two (2), four (4) and six (6) welded wire mesh and bolted back-to-back. The result of the study showed satisfactory outcomes in the performance of flexural strengths, however, the beam has not reached ductility behavior which is expected in reinforced concrete beams. However, the ferrocement I-beams show a single crack at failure and its ductile behavior is not yet attained.

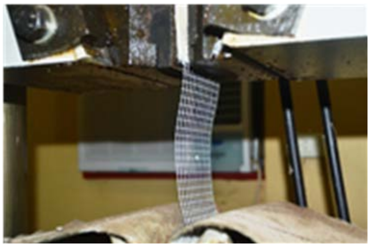
The purpose of this study is to improve the practical use of the ferrocement I-beams by attempting to develop its ductile behavior. Specifically: (a) it aims to obtain the properties of aggregates and the compression properties of ferrocement mortar used in casting the ferrocement I-beams; (b) to determine the tensile characteristics of welded wire mesh available in local hardware to be used in the study; (c) to evaluate the actual flexural capacity of the ferrocement I- beam with additional layers of wire mesh in the flange section as compared to the theoretical analysis computation; and, (d) to examine the cracking behavior of the ferrocement I-beam at failure showing the development of its ductile behavior.

2. Methodology

Aggregates used passed two stages of sieving. First stage was to separate the coarse aggregate from the fine aggregates using ¼” sieve. The fine aggregates are then passed through 2.32 mm sieves and washed with running water in order to eliminate the silts present in the aggregate. The washed aggregates are then air dried and placed in plastic bags in preparation for the different activities in the research. Approximately five kilograms of aggregates are prepared for sieve analysis. The sample is passed through a sample splitter four times in order to obtain its representative. Sets of mechanical sieves were used to determine soil gradation corresponding to ACI 549.1-93 recommendation.

Welded wire mesh procured from local hardware was evaluated of its actual tensile stress. Welded wire mesh with ½" x ½" opening and wire diameter of 0.66 mm were prepared into specimen 75 mm width and 300 mm length, both ends were encapsulated with mortar providing a 75 mm x 75 mm surface area and 10 mm thick for clamping allowing a free welded wire mesh of 150 mm length. This set of specimen was used to evaluate tensile strength of welded wire mesh. Another set of welded wire mesh are encapsulated with 10 mm thick mortar. In order to add strength to the ferrocement where clamping is required, additional two layers were provided. This specimen was used to evaluate tensile strength of ferrocement. Mortar was prepared with 1:2 cement aggregate ratio and 0.45 water-cement ratio, all measurement were taken by weight. Three replications of each set of specimen were prepared. In order to determine the properties of concrete, six specimens of mortar with cubic dimensions of 50 mm are prepared and cured together with the beam specimens. Routine test is shown in Figure 1.

a) Compression test of cement mortar



b) Tensile test of welded wire mesh

c) Tensile test of ferrocement

Figure 1. Routine test conducted to determine the physical properties of materials

The ferrocement I-Beam was composed of two Channel-shaped ferrocement beams installed back-to-back and connected with four-10 mm A325 bolts. The general form of the specimens is shown in Figures 1 and 2. The C- beams were generally reinforced with eight layers of ½” x ½” x 0.66 mm diameter welded wire mesh. Three treatments with three replications each were prepared for the study: Treatment T1 is provided with two additional layers of welded wire mesh along the flange section; Treatment T2 is provided with four additional layers of welded wire mesh along the flange section; Treatment T3 is provided with six additional layers of welded wire mesh along the flange section. The cement – sand – water ratio for mortar is a design mix of Type Ip Portland cement (conforming to ASTM C 150) to fine aggregate to mixing water of 1:2:0.45 measured by weight. In casting the beam specimen, the mortar was mixed thoroughly for 1-1/2 minutes. A vibrating table was used in order to facilitate compaction of the concrete mortar in the wooden mold fabricated for the purpose. Prior to casting, the inside of the wooden mold was applied with oil for the safety and easy removal of the ferrocement beam. Demoulding of the casted specimen was done 24+/- 4 hours after casting. Curing by ponding in a curing tank for 28 days followed. After 28 days, the cured cubic mortar, the ferrocement tensile section, the mortar encapsulated wire mesh for tensile testing and the ferrocement C-beam were unloaded from the curing tank and prepared for testing. The properties of the specimens were measured such as included dimensions and weights. Prior to testing, all beam specimens were painted with white latex paint so that any cracks that will be developed during testing can easily be recognized. Each pair of ferrocement Channel -beams were attached back-to-back to form the desired ferrocement I-Beam using four – 10 mm diameter A-325 bolts at specified location as shown in Figures 2 and 3 and locked in a way that the spacer in between will be less than 5 mm.

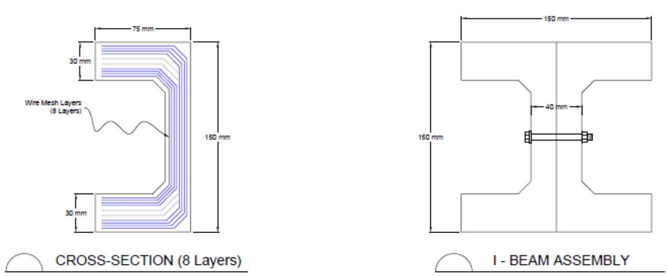


Figure 2. Cross-Sectional Details of the Assembly of Ferrocement I – beam Test Specimen. The web thickness excludes a 5mm spacer which this hold inconsistency of the back of the Channel - beam when connected by bolting.

Testing was done using a Universal Testing Machine. Tests include compression test for the mortar specimen, tensile tests of the wire mesh and ferrocement plate and flexural strength test of the ferrocement I-Beam. Test for tensile test of ferrocement followed the suggested procedure recommended by Naaman (2000).

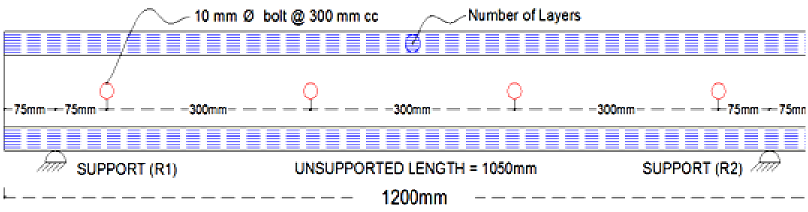


Figure 3. Longitudinal Details of the Assembly of Ferrocement I – beam Test Specimen.

The overall span of the prefabricated ferrocement I-beam is 1200mm and during testing the placement of the supports is located 75mm both ends of span which totals the unsupported length of 1050mm. The four (4) bolts connecting both Channel-beams were located 75mm from the support at a spacing of 300mm each

Test to determine compression of hydraulic cement mortars conformed to ASTM C 109/C 109M-02 (Standard test method for compressive strength of hydraulic cement mortars using 50 mm cube specimens). Test for flexural strength of beam conformed to ASTM C78-02 (Standard test method for flexural strength of concrete using simple beam with third-point loading).

3. Results and Discussions

3.1 Properties of Fine Aggregates

Result of the soil gradation test is shown in Table 1. The soil gradation is then compared to the recommended gradation as per ACI 549.1-93 and result is shown graphically in Figure 4. It is noted that the fine aggregates used conformed to ACI 549.1-93 specifications.

Table 1. Actual gradation of fine aggregates compared to recommended gradation

Sieve Number	Sieve Opening (mm)	Mass Retained (g)	Cumulative Mass Retained (g)	Percent Finer (%)	Recommended Gradation (%)
8	2.360	64	64	93.77	80-100
16	1.180	226	310	71.76	50-85
30	0.600	135	415	58.62	25-60
50	0.355	423	901	17.43	15-45
60	0.250	----	----	----	10-30
100	0.150	126	994	5.16	2-10
Pan	----	53	1027	----	----

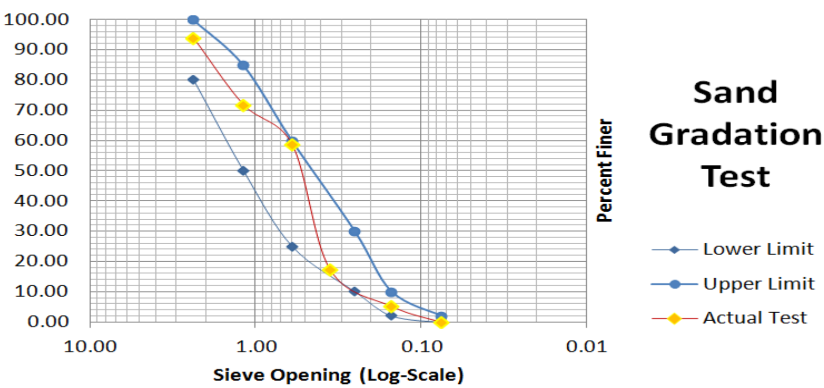


Figure 4. Gradation test result of fine aggregates

3.2 Compression Properties of Concrete Mortar

Results of the compression test of cubic mortars are given in Table 2. The computed average compressive strength of the mortar is 41.97 MPa. The average unit weight of the mortar was computed to be 2,643.2 kg/m^3. The modulus of elasticity of the mortar is determined using the equation $E_c = \left[3320\sqrt{f'_c} + 6895\right]\left(\frac{w_c}{2320}\right)^{1.5}$ where f'_c is the compressive strength of the mortar in MPa while w_c is the unit of the mortar in kg/m^3, so that E_c value to be used in this study is computed to be 34,540.85 MPa.

Table 2. Compression test results of the cement mortar in MPa.

Cube No.	Treatment 1	Treatment 2	Treatment 3	Average
1	45.34	52.24	42.46	46.68
2	33.12	34.93	32.86	33.37
3	42.16	39.63	38.35	40.05
4	38.52	48.16	41.56	42.75
5	51.06	54.32	41.40	48.92
6	39.74	37.02	43.44	40.07
Average	41.66	44.38	40.01	41.97

3.3 Tension Properties of Welded Wire Mesh and Ferrocement Plates

The welded wire mesh used for tensile test has seven wires per specimen providing a cross-sectional area of 2.3948 sq. mm. The same sizes of wire meshes were encapsulated with 10 mm thick of mortar in order to determine the tensile strength of ferrocement. The gripping surfaces were provided with additional wire mesh for added strength and to assure that failure will occur only in the free surface. Figure 1b shows the set-up for the tensile test of welded wire mesh while Figure 1c shows the tensile test set-up for ferrocement. Result of the test is summarized in Table 3.

Table 3. Summary of result of Tensile Test of welded wire mesh and ferrocement plate.

Specimen	Tensile Stress (σ_{ty}) in MPa	Average Tensile Stress (MPa)
Welded wire mesh (1/2 ” x 1/2” x 0.66 mm diameter)		
11	555.57	492
12	461.83	
13	460.00	
Mortar encapsulated welded wire mesh		
21	525.30	544
22	535.30	
23	574.50	

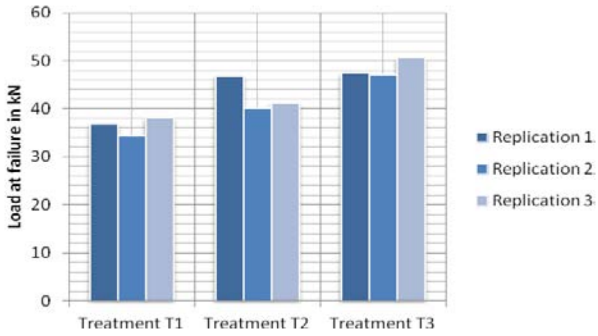


Figure 5. Load at failure at three treatments of Ferrocement I-Beam

3.4 Flexural Strength of Ferrocement I-Beam

Result of load at failure of the three treatments of ferrocement I-Beam is shown in Figure 5. As the number of layers of welded wire mesh reinforcement in the flange area is increased from 8 layers and additional two layers increased per treatment, the load at failure also increased. A marked increase in the capacity is thus noted.

3.5 Cracking Behavior of Ferrocement I-Beam

The cracking behavior of the ferrocement I-Beam at failure can be briefly described as follow:

a) In treatment T1 where the ten layers of welded wire mesh reinforcement is provided in the flange section, each replicated showed a visible single crack and each crack appeared in or near the middle third of the span where the load was applied;

b) In treatment T2 where the twelve layers of welded wire reinforcement is provided in the flange section, each replicate showed a visible, multiple cracks and each crack are found in the middle third of the span where the load was applied; and,

c) In treatment T3 where the fourteen layers of welded wire reinforcement is provided in the flange section, each replicate showed a visible, multiple cracks and each crack are found in the middle third of the span where the load was applied.

a) Treatment T1

b) Treatment T2

c) Treatment T3

Figure 6. Cracking pattern of the ferrocement I-Beam subjected to third-point loading

The cracking pattern showed that the beam in Treatment T1 has not showed yet its ductility behavior. However, such characteristic was already exhibited starting with Treatment T2. The visual presentation of the cracking pattern is shown in Figure 6.

4. Conclusions and Recommendation

From the results of the tests conducted, the following conclusions were drawn:

a) The compressive strength of the ferrocement mortar was satisfactory;

b) The welded wire mesh sold in the Philippine market passed the required material properties, hence, it can be used in the ferrocement applications;

c) There is a marked increase in the capacity of the ferrocement I-Beam as the number of layers of wire mesh reinforcement in the flange area is increased from 8 layers and additional two layers increased per treatment. The load at failure of the beam increased from an average of 35 kN for 8 layers, 42.33 kN for 10 layers and 48 kN for 12 layers; and,

d) There is also increasing number of cracks in the flange section as the number of layers of welded wire reinforcement signifying that the beam is already showing ductility behavior.

Further study is still needed to improve further the capability of the ferrocement I- Beam and this include providing additional number of layers of welded wire mesh in the flange section; the shear strength analysis of the beam section and the development of an empirical equation that can be used in the structural design of the beam section.

5. Acknowledgement

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6. References

ACI 549R – 97. State – of – the – Art Report on Ferrocement. American Concrete Institute. 1997.

ACI 549.1 93. State – of – the – Art Report on Ferrocement. American Concrete Institute. 1993.

ACI C78. Standard Test Method for Flexural Strength of Concrete (Using Beam with Third-Point Loading). American Concrete Institute.

Acma, Leoncio and Mariano, C., (2014). Development and Application of Ferrocement I-beams. Doctor of Engineering Dissertation. Philippines: MSU-IIT, Iligan City.

ASTM C150 – 95a. Specifications for Portland Cement. American Society of Testing of Materials. 1995.

ASTM C109/C109M-02. Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2 in. or 50 mm) Cube Specimens. American Society of Testing of Materials. 2002.

ASTM C78-02. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). American Society of Testing of Materials. 2002.

Naaman, A.E., (2000). Ferrocement and Laminated Cementitious Composites. Ann Arbor, Michigan. Techno Press 3000.